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Research Article

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Impact of damming on water quality in tropical semiarid rivers

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Abstract

Reservoirs are widely recognized for altering river water quality through physical, chemical, and biological processes. However, their integrated effects on multiple water quality indicators remain poorly quantified, particularly in tropical semiarid basins affected by prolonged droughts. This study evaluated the influence of damming on 15 water quality parameters using long-term monitoring data from eight reservoirs in the Brazilian semiarid region, encompassing a severe multiyear drought during which reservoir storage declined to up to about 1% of capacity. Reservoir effects were quantified using outlet-to-inlet (O/I) parameter ratios. The O/I values exhibited substantial intra-annual variability, alternating between net attenuation and net enrichment in response to hydrological conditions, but remained remarkably stable over the long term despite pronounced fluctuations in reservoir storage. Most parameters, including pH, water temperature, color, electrical conductivity, total dissolved solids, salinity, biochemical oxygen demand, chemical oxygen demand, thermotolerant coliforms, and total phosphorus, exhibited only minor net changes (O/I within $\pm 10\%$). In contrast, total inorganic nitrogen, total suspended solids, dissolved oxygen, turbidity, and chlorophyll-a increased by 31%, 35%, 41%, 69%, and 130%, respectively, indicating enhanced phytoplankton productivity driven by the preferential retention of phosphorus relative to nitrogen. The observed temporal behavior was independently supported by a hydrological and phosphorus model, which reproduced the measured O/I ratios (NSE = 0.42; PBIAS = 8%) and demonstrated through scenario simulations that different combinations of reservoir storage and internal decay rates can explain the contrasting O/I responses observed among the 15 water quality parameters. Overall, the results indicate that prolonged droughts influence the intra-annual variability of O/I ratios but have little effect on their long-term behavior. Additionally, tropical semiarid reservoirs do not function as treatment systems capable of substantially removing organic matter, microbial contamination or nutrients, as reported in previous studies. Instead, they exert only minor net effects on most water quality parameters while promoting net increases in inorganic nitrogen, suspended solids, dissolved oxygen, turbidity, and chlorophyll-a, driven by external pollutant inputs associated with limited erosion/diffuse pollution control and inadequate sanitation infrastructure.

Keywords: dam impacts; outlet-to-inlet ratio; eutrophication; drought; phytoplankton; nutrient dynamics

1. Introduction

Freshwater quality has become an increasing global environmental concern due to rapid population growth, urbanization, agricultural intensification, reservoir construction and climate change (Raulino et al., 2021; van Vliet et al., 2023; Wang et al., 2024; Shi et al., 2026). These pressures have substantially altered the transport, transformation and retention of nutrients, organic matter, sediments and pathogens, threatening ecosystem integrity, drinking water security and economic development (Javed et al., 2022; Jones et al., 2022; Russ et al., 2024; Costa et al., 2025). Reservoirs play a particularly important role because they interrupt natural river continuity, modify flow regimes, promote sedimentation and alter biogeochemical cycling. As a result, damming can either improve or deteriorate downstream water quality depending on hydrological conditions, nutrient availability and reservoir characteristics. Understanding these processes has therefore become essential for sustainable water resources management, especially in regions where reservoirs constitute the primary source of water supply.

Although the impacts of dams on river hydrology have been extensively investigated, their effects on water quality have generally been assessed using only a limited number of indicators, most commonly temperature, sediment, and nutrients (Lima Neto et al., 2011; Maavara et al., 2020; Winton et al., 2019; Shi and Qin, 2023; Gan et al., 2025). However, reservoir passage simultaneously influences a wide range of physical, chemical, biological, and microbiological variables through interconnected processes, including thermal and chemical stratification, sedimentation, nutrient cycling, primary production, organic matter decomposition, microbial transformations, among others (Deus et al., 2013; Sadeghian et al., 2018; Zhang et al., 2018; Lindenschmidt et al., 2019; Fraga et al., 2020; Lima Neto, 2023, 2025b). As these processes interact, changes in individual parameters may not adequately reflect the overall response of aquatic ecosystems to reservoir impoundment. Comprehensive, multi-parameter assessments are therefore essential to improve understanding of reservoir functioning and to support more effective water quality management.

This knowledge gap is particularly relevant in densely populated tropical semiarid regions, such as northeastern Brazil, where reservoirs sustain urban water supply, irrigation, and economic activities despite highly variable hydroclimatic and land use/cover conditions that strongly influence external and internal fluxes of organic matter, microbes, and nutrients, as well as overall water quality dynamics (Rocha and Lima Neto, 2021, 2022, 2023; Rocha et al., 2024a,b; Freire et al., 2025a,b; Porto et al., 2026). Prolonged droughts can reduce reservoir storage to only a small

fraction of its capacity, while high evaporation rates and elevated temperatures promote eutrophication, complex nutrient transformations, and harmful algal blooms (Carneiro et al., 2023; Guimarães et al., 2023; Lima Neto, 2026). Despite the large number of reservoirs operating in tropical drylands, research on how damming modifies multiple water quality variables, and on whether these responses are altered under extreme drought conditions, is still lacking. Addressing this knowledge gap is essential for developing effective reservoir management strategies to cope with increasing water scarcity and climate variability.

The objective of this study was to quantify the effects of damming on a comprehensive set of water quality parameters using long-term monitoring data from eight reservoirs in the Brazilian semiarid region, encompassing a prolonged and severe drought during which reservoir storage declined dramatically. Reservoir impacts were assessed using outlet-to-inlet (O/I) parameter ratios for fifteen physical, chemical, biological, and microbiological variables, including pH, water temperature, color, electrical conductivity, total dissolved solids, salinity, nutrients, organic matter indicators, suspended solids, dissolved oxygen, chlorophyll-a, and thermotolerant coliforms. By identifying which water quality variables remain relatively stable and which undergo substantial modification during reservoir passage, this study provides new insights into the role of tropical semiarid reservoirs as regulators of river water quality and evaluates whether these effects are altered under prolonged drought conditions. The observed patterns were further interpreted and independently supported using the hydrological and water quality model developed by Lima Neto (2025b). The findings provide a scientific basis for improving reservoir operation, watershed management, and eutrophication control in water-scarce environments.

2. Methodology

The study was conducted in eight reservoirs in Ceará State, northeastern Brazil, one of the world's largest tropical semiarid regions, as shown schematically in Figure 1. The investigated reservoirs, Angicos, Araras, Atalho, Banabuiú, Castanhão, Mundaú, Orós, and Pentecoste, play key roles in regional water supply, irrigation, and flood control and are operated by the Ceará Water Resources Management Company (COGERH). Castanhão and Orós, the largest reservoirs in the Ceará State, are also used for fish-farming. These eight dams were selected because long-term water quality monitoring data were available for river sections immediately upstream and downstream of each reservoir through monitoring programs conducted by the Ceará State Environmental Agency (SEMACE). Together, these reservoirs span a broad range of storage capacities, trophic states, and watershed characteristics, providing a representative sample of

tropical semiarid reservoir systems. The main characteristics of the studied reservoirs are summarized in Table 1.

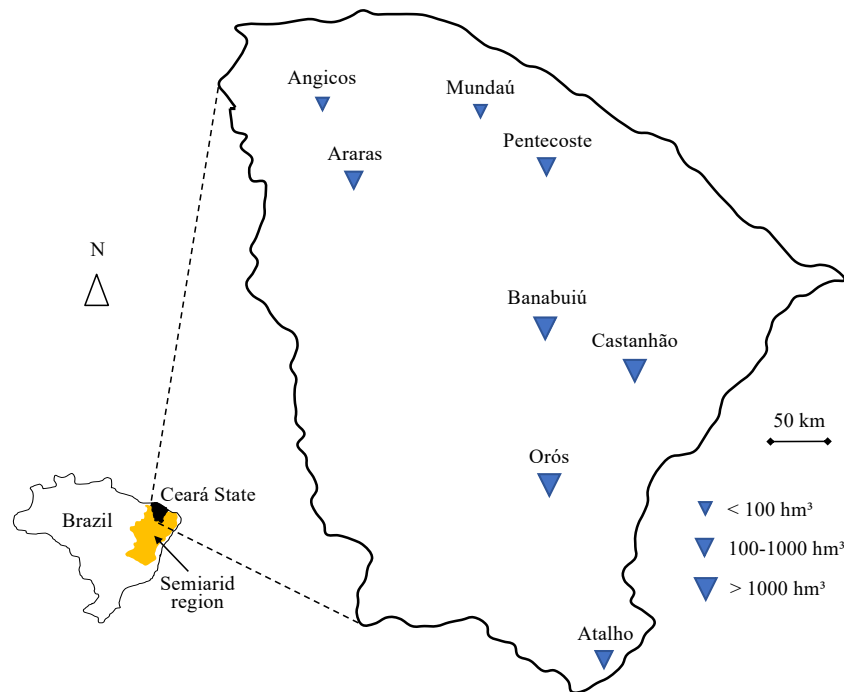


Figure 1. Location of the studied reservoirs in the Ceará State, Brazilian semiarid region.

Table 1. Main characteristics of the studied reservoirs.

Characteristic	Reservoir							
	Angicos	Araras	Atalho	Banabuiú	Castanhão	Mundaú	Orós	Pentecoste
Basin	Coreaú	Acaraú	Salgado	Banabuiú	Médio Jaguaribe	Litoral	Alto Jaguaribe	Curu
Capacity (hm³)	56	860	108	1601	6700	21	1940	360
Volume (%)	59	85	17	14	23	71	36	25
Trophic State	Eutrophic / Hypereutrophic	Eutrophic / Hypereutrophic	Eutrophic / Mesotrophic	Eutrophic / Mesotrophic	Eutrophic	Eutrophic / Mesotrophic	Eutrophic	Eutrophic / Hypereutrophic

The regional climate is characterized by high temperatures throughout the year, mean annual rainfall ranging from approximately 500 to 900 mm, and pronounced seasonality, with most precipitation concentrated between February and May (Raulino et al., 2021; Freire et al., 2025). Recurrent droughts frequently reduce river inflows and reservoir storage, creating favorable conditions for eutrophication and altered nutrient cycling (Rocha et al., 2024a,b; Lima Neto, 2025a,b). During the study period, the region experienced one of the most severe droughts on record, with reservoir storage volume declining to historic minimum levels (as low as approximately 1% of total capacity) between 2015 and 2019, followed by a period of storage recovery, as depicted in Figure 2. Data were obtained from COGERH.

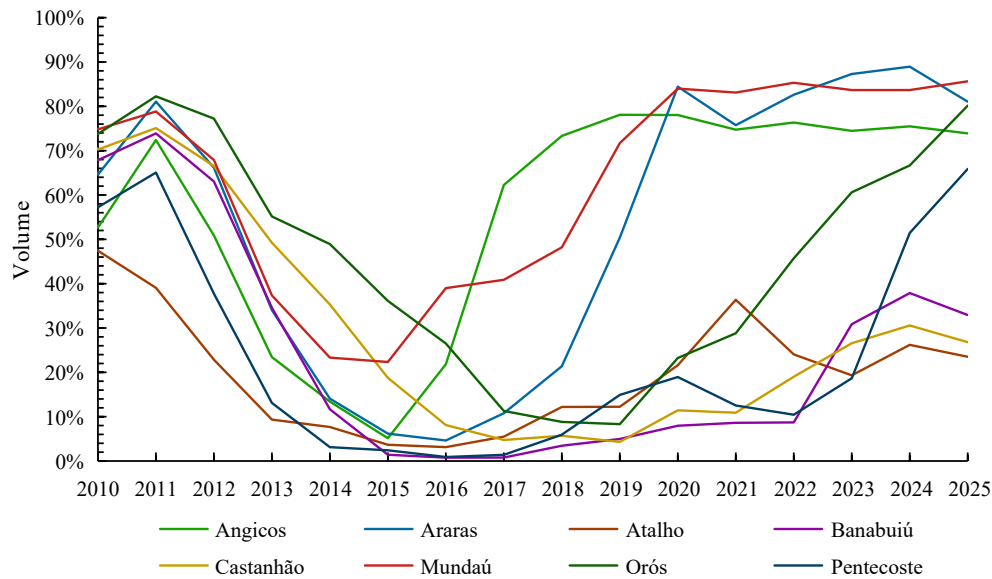


Figure 2. Temporal variation in reservoir storage volume (% of total capacity) during the study period, showing historic minimum levels (as low as approximately 1% of total capacity) between 2015 and 2019 due to the severe drought.

Water quality data were obtained from the long-term monitoring programs conducted by SEMACE. For each reservoir, paired monitoring stations located immediately upstream (reservoir inflow) and downstream (reservoir outflow) of the dam were selected to quantify the effects of reservoir passage on water quality. Only paired sampling campaigns in which inflow and outflow measurements were available within the same monitoring campaign were included in the analysis. The dataset comprised time series spanning approximately 4 to 15 years of monitoring, with record lengths varying among reservoirs according to data availability.

Water samples were collected and analyzed by SEMACE following routine field and laboratory procedures in accordance with the Standard Methods for the Examination of Water and Wastewater (APHA, 2017). Fifteen water quality parameters representing physical, chemical, biological and microbiological conditions were determined: pH, water temperature, true color, electrical conductivity (EC), total dissolved solids (TDS), salinity, total suspended solids (TSS), dissolved oxygen (DO), biochemical oxygen demand (BOD), chemical oxygen demand (COD), thermotolerant coliforms, total phosphorus (TP), total inorganic nitrogen (TIN), turbidity and chlorophyll-a (Chla).

Reservoir effects on water quality were evaluated using the outlet-to-inlet (O/I) ratio, defined as the ratio between measurements at the reservoir outflow and inflow. The O/I ratio provides a dimensionless measure of the integrated effect of reservoir passage on each water quality parameter. The O/I ratio was calculated for each paired sampling campaign and subsequently averaged for each reservoir and water quality parameter. Temporal variability of O/I ratios was also

evaluated to examine the consistency of damming effects under contrasting hydrological conditions, including the prolonged drought period. The observed O/I patterns were further interpreted and independently supported by using the hydrological and TP model developed by Lima Neto (2025b).

Based on the average O/I ratios, parameters were classified into three categories: (i) little net change (variation within approximately $\pm 10\%$ of unity), (ii) moderate increase or decrease (20-50%), and (iii) strong increase or decrease ($> 50\%$). This classification facilitated comparisons among reservoirs and among different groups of water quality indicators. The results were subsequently compared with previous studies on reservoir biogeochemistry and damming impacts on river water quality to assess the extent to which tropical semiarid reservoirs exhibit responses similar to those reported in other regions of the world.

3. Results and discussion

Table 2 summarizes the mean inflow water-quality characteristics of the eight reservoirs. While conservative variables, such as pH and water temperature, varied only slightly among reservoirs, substantial differences were observed for turbidity, color, suspended solids, nutrients, organic matter indicators, and microbiological variables, reflecting the contrasting hydrological, geological, and land-use characteristics of their contributing watersheds, as reported by Rocha and Lima Neto (2021) and Freire et al. (2023). No single reservoir consistently exhibited the highest values across all parameters. Orós was characterized by the highest mean turbidity, Chla, and TSS, whereas Araras exhibited the highest TIN, BOD, and COD. Banabuiú showed the highest TP, TDS, and thermotolerant coliform concentrations, while Atalho and Castanhão exhibited the highest color and DO values, respectively. Overall, these results demonstrate the broad range of inflow water-quality conditions represented in this study, providing a robust basis for evaluating the effects of damming across contrasting tropical semiarid systems.

Table 2. Mean inflow water-quality characteristics of the studied reservoirs.

Parameter	Reservoir							
	Angicos	Araras	Atalho	Banabuiú	Castanhão	Mundaú	Orós	Pentecoste
pH	7.55	8.01	7.63	7.90	8.35	7.37	8.08	7.31
Turbidity (uT)	27.90	25.51	43.04	8.13	28.93	23.39	127.85	9.64
Color (uH)	93.09	132.38	150.73	94.83	67.68	118.71	112.11	68.21
Temperature (°C)	30.15	28.82	28.15	28.72	30.30	27.85	29.24	29.21
TIN (mg/L)	0.75	7.31	1.28	3.51	0.74	1.51	2.88	1.09
DO (mg/L)	7.56	3.73	6.09	5.81	7.80	5.70	7.28	4.53
BOD (mg/L)	2.88	40.10	5.37	7.41	7.30	3.16	9.82	4.35
COD (mg/L)	27.35	306.26	27.03	51.24	21.55	15.56	82.53	44.62
EC (µS/cm)	348.29	33.46	313.18	806.29	385.90	216.28	754.52	690.28
Chla (µg/L)	4.39	0.38	24.44	7.51	3.16	13.95	48.31	8.37
TP (mg/L)	0.16	0.17	0.35	1.14	0.31	0.40	0.94	0.27
Salinity (‰)	0.93	0.15	0.14	0.88	0.17	0.10	0.38	0.34
TSS (mg/L)	10.56	19.77	18.10	7.46	23.65	18.33	30.70	19.72
TDS (mg/L)	216.54	202.12	175.02	442.00	223.65	198.54	391.25	406.56
Coliforms (MPN/100mL)	452.18	427.22	140.84	3224.67	351.36	1539.86	1762.57	844.88

Figure 3 presents the temporal evolution of the outlet-to-inlet (O/I) ratios for the 15 water quality parameters across the eight investigated reservoirs. Because of their substantially greater variability, thermotolerant coliform concentrations were log-transformed. Overall, the O/I ratios exhibited considerable temporal variability, with several parameters alternating between net attenuation ($O/I < 1$) and net enrichment ($O/I > 1$) throughout the study period, reflecting shifts in the balance between source and sink processes. Despite these fluctuations, the ratios generally returned to values similar to those observed at the beginning of the monitoring period following the recovery of reservoir storage after the prolonged drought (see Figure 2). This pattern indicates that, although reservoir functioning responded to interannual hydrological variability, its long-term net effects on water quality remained broadly stable, suggesting that compensating internal processes largely offset the influence of substantial fluctuations in reservoir storage.

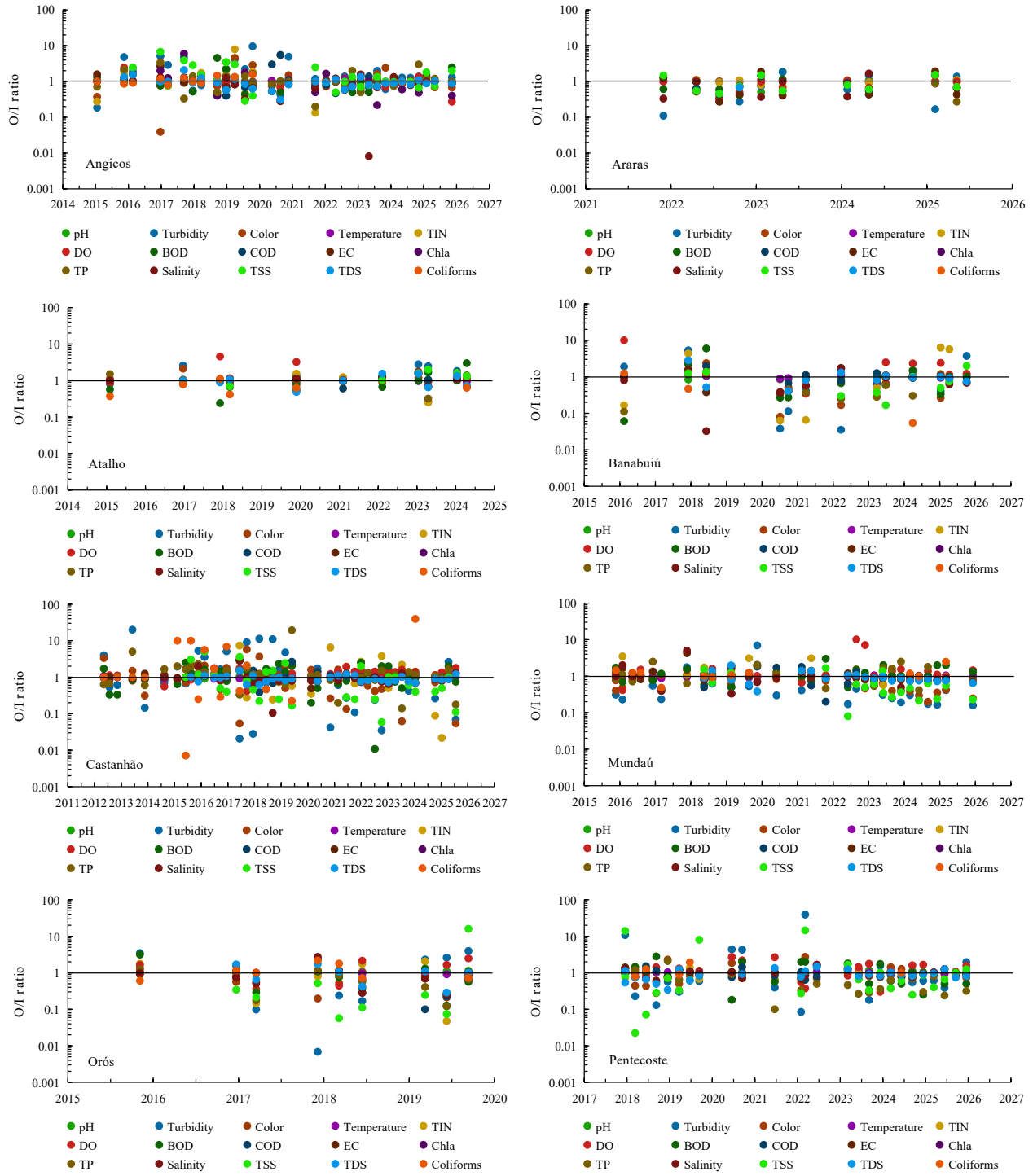


Figure 3. Temporal evolution of the outlet-to-inlet (O/I) ratios for the 15 water quality parameters in each of the eight studied reservoirs.

Figure 4, based on the hydrological and total phosphorus (TP) model of Lima Neto (2025b) for the Castanhão reservoir, provides mechanistic support for the interpretation above. Reservoir storage and water residence time (RT) exhibited similar long-term temporal patterns ($R^2 = 0.62$), both decreasing during the prolonged drought (2012-2018) and increasing during the subsequent recovery period (2019-2023) (Figure 4a). Such changes would be expected to reduce the reservoir's

dilution capacity and TP retention during drought conditions while enhancing these processes as storage recovered. However, the simulated net internal TP flux, representing the balance between phosphorus input and output loads, fluctuated around zero throughout the study period, with only episodic deviations associated with individual hydrological events rather than a persistent long-term trend (Figure 4b). Consequently, the simulated O/I ratio exhibited a moderate dependence on reservoir storage ($R^2 = 0.44$), but only modest long-term variations despite the pronounced changes in reservoir storage, remaining close to unity for most of the simulation period (Figure 4c). This interpretation is supported by simulations using the model developed by Lima Neto (2025b), which reproduced the independent outlet-to-inlet (O/I) TP data presented in this study with satisfactory accuracy, yielding a Nash-Sutcliffe Efficiency (NSE) of 0.42 and a percent bias (PBIAS) of 8%. According to the performance criteria of Moriasi et al. (2015), these values correspond to “satisfactory” and “very good” model performance, respectively. The above results indicate that changes in reservoir storage influenced the O/I ratio, but that compensating phosphorus cycling processes largely limited the magnitude of these changes. During wet periods, higher reservoir storage increased dilution capacity and TP retention through longer residence times (Rocha et al., 2024a). At the same time, however, higher inflows enhanced external TP loading through watershed wash-off (Rocha et al., 2021), while greater water depths and stronger thermal/DO stratification promoted sediment phosphorus release, thereby increasing internal loading (Carneiro et al., 2023). Conversely, during prolonged droughts, external TP inputs were substantially reduced because of limited runoff, and the shallower, well-mixed water column largely suppressed thermal/DO stratification and associated internal phosphorus release (Lima Neto et al., 2022). Although dilution capacity and TP retention were also reduced under these conditions, the simultaneous decreases in both external and internal phosphorus loading largely offset these effects. As a result, the O/I ratio exhibited only modest long-term variability despite the substantial fluctuations in reservoir storage, highlighting the resilience of the reservoir’s net effect on TP concentrations under contrasting hydrological conditions.

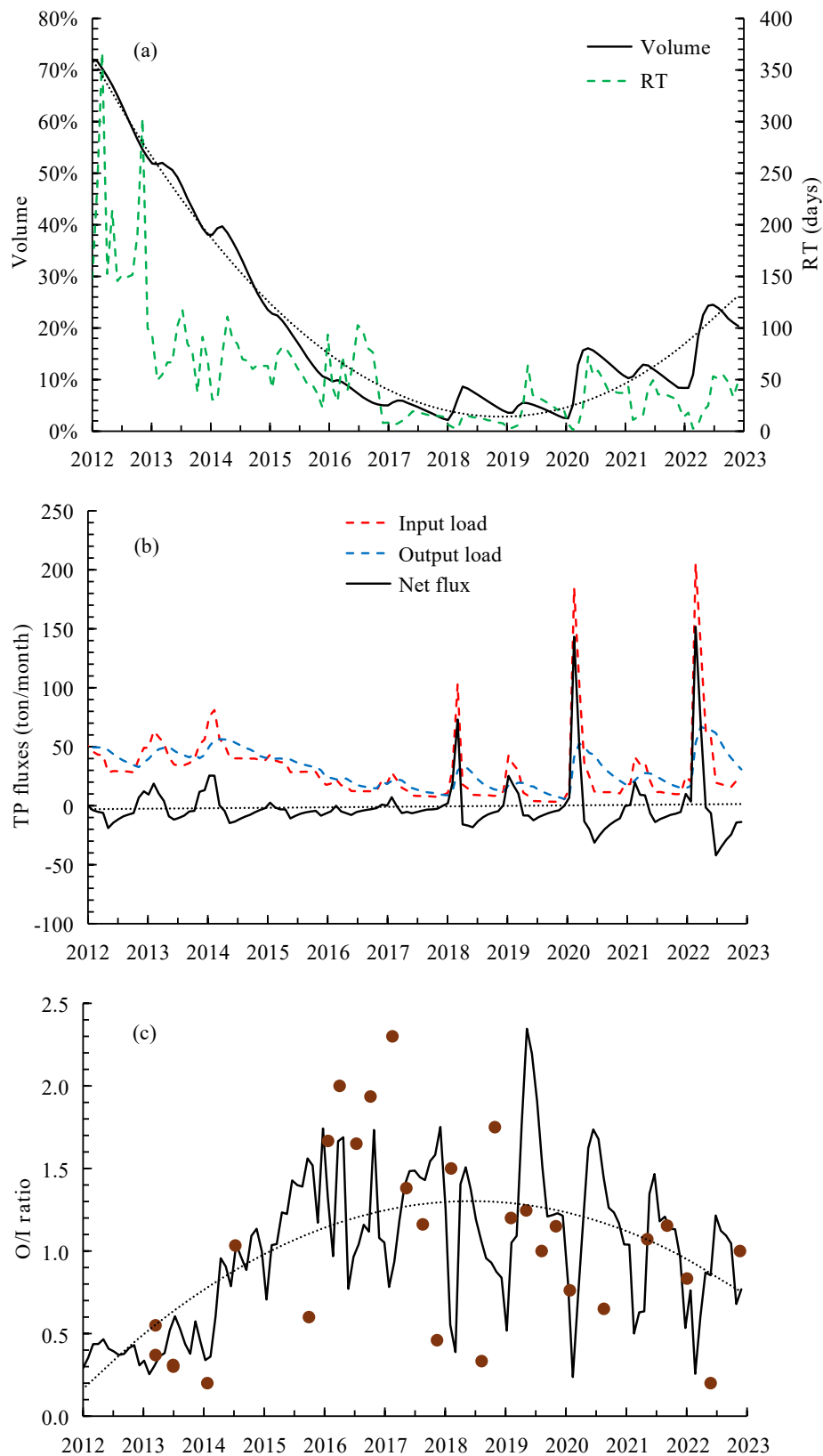


Figure 4. Long-term temporal patterns for the Castanhão reservoir: (a) reservoir volume and water residence time; (b) simulated net internal TP flux, represented by the difference between phosphorus input and output loads; and (c) simulated and observed outlet-to-inlet (O/I) ratios. Dotted lines represent fitted curves describing the long-term trends in reservoir storage, net internal TP flux, and O/I ratio.

Figure 5 presents scenario simulations of the effects of different combinations of reservoir volume and TP decay rates on the outlet-to-inlet (O/I) ratio using the model of Lima Neto (2025b), as compared with the baseline simulations shown in Figure 4(c). The results indicate that decreasing the TP decay rate by 50% and reservoir volume by 25% consistently reduces the reservoir's removal efficiency and dilution capacity, thereby increasing the average O/I ratio to 2.60 and 1.22, respectively. Conversely, increasing the TP decay rate by 50% and reservoir volume by 25% enhances removal efficiency and dilution capacity, resulting in average O/I ratios of 0.54 and 0.83, respectively. Notably, the simulated O/I values encompass approximately the range of responses observed for the 15 water quality parameters shown in Figure 3, demonstrating that different combinations of reservoir volume and internal transformation rates can mechanistically explain the contrasting attenuation and enrichment patterns among these parameters.

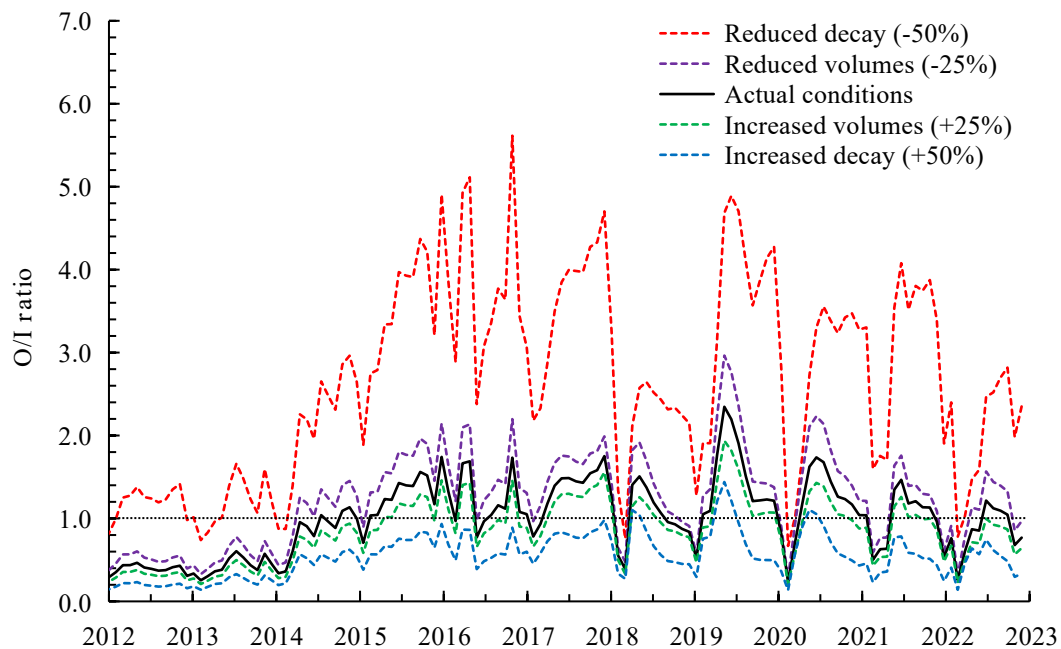


Figure 5. Scenario simulations illustrating the effects of different combinations of reservoir volume and decay rate on the outlet-to-inlet (O/I) ratio, compared with the baseline simulations shown in Figure 4c.

Figure 6 summarizes the average outlet-to-inlet (O/I) ratios for the 15 water quality parameters across the eight investigated reservoirs. Consistent with the long-term temporal analysis presented above, no clear relationship was observed between the average O/I ratios and reservoir volume, despite the large differences in storage capacity among the reservoirs (Figure 2). Approximately two-thirds of the analyzed parameters exhibited average O/I ratios close to unity, indicating that damming had only a minor net effect on water quality. In contrast, TIN, TSS, DO, turbidity, and Chla consistently deviated from unity, reflecting substantial internal transformations and net enrichment during reservoir passage. These findings indicate that, despite becoming

considerably shallower during prolonged droughts, tropical semiarid reservoirs do not function as treatment systems comparable to waste stabilization ponds, which are capable of substantially removing organic matter, nutrients, and microbial contamination (Araújo and Lima Neto, 2019; Fraga et al., 2020; Rocha et al., 2022). Instead, these reservoirs exert only limited net effects on most water quality parameters while promoting net enrichment of inorganic nitrogen, suspended solids, dissolved oxygen, turbidity, and chlorophyll-a, primarily through internal biogeochemical processes. It is important to note that the high dissolved oxygen O/I ratio reflects the daytime sampling conducted by SEMACE and therefore indicates intense phytoplankton photosynthesis driven by nutrient enrichment rather than good water quality. In eutrophic systems, this daytime oxygen supersaturation is often followed by nighttime oxygen depletion due to community respiration, resulting in pronounced diel oxygen fluctuations (Rocha et al., 2024b).

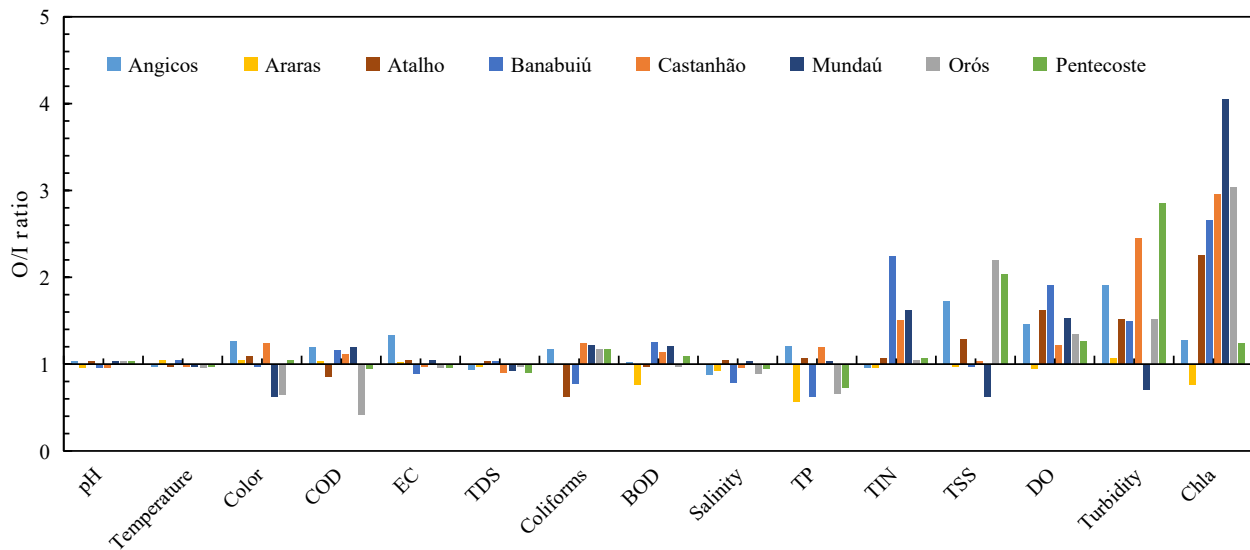


Figure 6. Average outlet-to-inlet (O/I) ratios for the 15 water quality parameters in each of the eight investigated reservoirs.

Figure 7 shows the average outlet-to-inlet (O/I) ratios for the 15 evaluated water quality parameters. Overall, most variables exhibited O/I ratios close to unity, indicating that reservoir passage resulted in only limited net changes in water quality conditions. Water temperature, pH, EC, salinity, TDS, color, BOD, COD, thermotolerant coliforms, and TP displayed near-conservative behavior, with outlet values differing by less than approximately $\pm 10\%$ from inflow values. These results indicate that thermal conditions, dissolved constituents, dissolved organic matter, organic matter degradation, microbial die-off, and phosphorus retention were only weakly modified by damming. As discussed for Figure 4, phosphorus retention was largely compensated by external and internal loadings. Similarly, the effects of organic matter degradation and bacterial die-off were likely offset by watershed inputs and internal recycling, resulting in only modest net

changes. In contrast, only five parameters exhibited systematic deviations: inorganic nitrogen, total suspended solids, dissolved oxygen, turbidity, and chlorophyll-a increased by approximately 30%, 35%, 40%, 70%, and 130%, respectively. Consistent with the results of Lima Neto (2026), these responses indicate preferential phosphorus retention relative to nitrogen and enhanced phytoplankton production promoted by favorable high-temperature conditions (approximately 30 °C). Previous studies have similarly reported higher TP retention (>10%) than observed in the present study, attributing the preferential retention of phosphorus to stronger sedimentation and sorption processes compared with nitrogen, together with atmospheric nitrogen fixation (Maavara et al., 2020). Likewise, Wu et al. (2024), in a global analysis of more than 5,000 lakes, found that approximately 90% exhibited preferential phosphorus retention relative to nitrogen, while about 80% acted as net sinks for both nutrients. More recently, Gan et al. (2025) reinforced that reservoirs worldwide generally function as net sinks for both nitrogen and phosphorus, although phosphorus is retained more efficiently than nitrogen. In contrast, the reservoirs investigated here generally showed only slight net TP retention and a net enrichment of TIN. This suggests that TP retention was largely offset by continuous external nutrient inputs associated with limited control of erosion and diffuse pollution and inadequate sanitation infrastructure, as well as by intense internal nutrient cycling promoted by high-temperature conditions (Rocha et al., 2021, 2022; Lima Neto et al., 2022; Lima Neto, 2025a,b). Conversely, the significant enrichment of TIN is likely related to greater nitrogen production and transport in tropical semiarid catchments, combined with lower nitrogen decay rates within the reservoirs compared with TP (Rocha and Lima Neto, 2023; Lima Neto, 2026). These findings suggest that the dynamics of most investigated parameters followed patterns similar to the nearly-conservative behavior for TP, whereas TSS, DO, turbidity, and Chla exhibited responses more closely associated with the enrichment behavior of TIN. Note that the scenario simulations presented in Figure 5 captured adequately all observed behaviors shown in Figure 6: negligible net effects, net attenuation, and net enrichment.

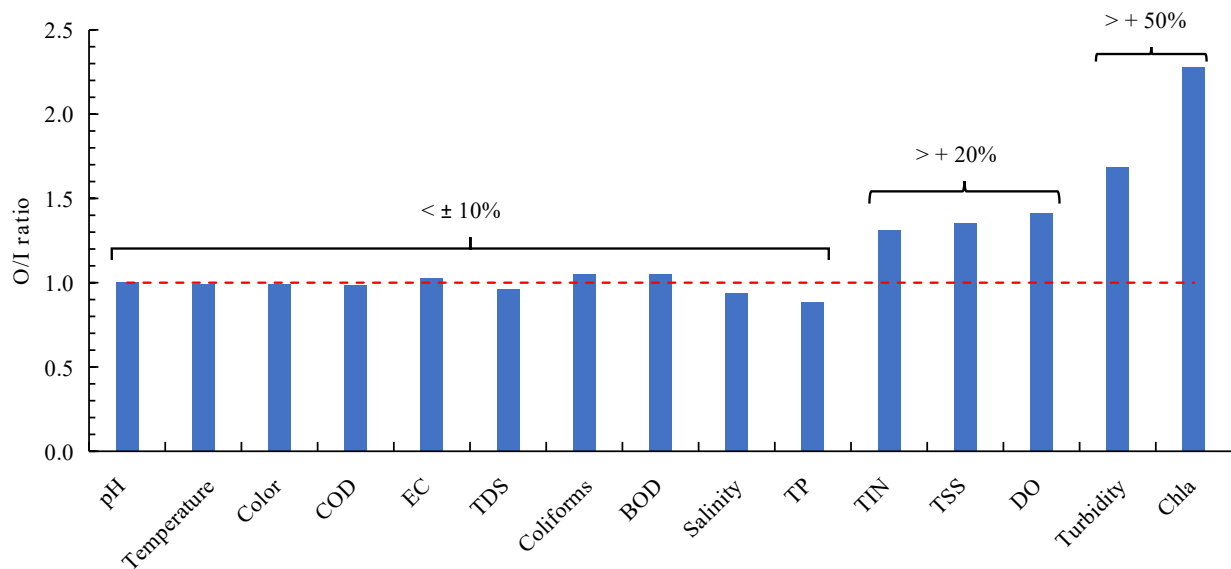


Figure 7. Average outlet-to-inlet (O/I) ratios for the 15 water quality parameters.

4. Conclusions

This study investigated the effect of damming on water quality in eight tropical semiarid river basins in Brazil. Outlet-to-inlet (O/I) ratios indicated that two-thirds of the 15 water quality parameters evaluated herein exhibited near-conservative behavior, whereas total inorganic nitrogen (TIN), total suspended solids (TSS), dissolved oxygen (DO), turbidity, and chlorophyll-a (Chla) showed systematic enrichment, reflecting enhanced phytoplankton productivity driven by the preferential retention of phosphorus relative to nitrogen. Although drought severity influenced intra-annual O/I variability, it had little effect on long-term patterns, which were primarily governed by external loading and internal biogeochemical processes. A calibrated and independently validated hydrological and TP model reproduced satisfactorily the observed O/I dynamics and was essential for assessing the mechanisms driving attenuation and enrichment across the 15 water quality parameters through scenario simulations. Contrary to previous studies, the investigated reservoirs generally exhibited only slight net TP retention and net TIN enrichment. This behavior suggests that TP retention was largely compensated by external TP inputs associated with limited control of diffuse pollution and inadequate sanitation infrastructure, as well as by high temperatures promoting intense internal TP cycling. Conversely, net TIN enrichment was likely related to higher nitrogen yields and transport in tropical semiarid catchments, combined with lower nitrogen decay rates within reservoirs compared with TP. Consequently, while most parameters followed patterns similar to the conservative behavior observed for TP, the variables TSS, DO, turbidity, and Chla exhibited responses more closely associated with the enrichment patterns observed for TIN. The

present study not only advances the understanding of the effects of damming on river water quality but also helps improve water resources management in tropical semiarid basins.

5. Declarations

- Ethics approval and consent to participate: Not applicable
- Consent for publication: Not applicable
- Availability of data and materials: Data available upon request
- Competing interests: The author declares that he has no competing interests
- Funding: The author appreciates the financial support from the National Council for Scientific and Technological Development - CNPq (#307680/2023-1) and the Coordination for the Improvement of Higher Education Personnel - CAPES (#2160/2024).
- Author's contributions: Iran Eduardo Lima Neto: Conceptualization, Formal analysis, Investigation; Methodology, Writing – original draft preparation, Project administration.
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